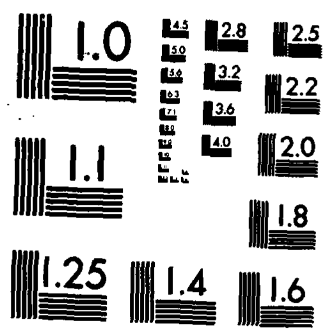
AD-A173 192 OPTICAL TECHNIQUE FOR THE MEASUREMENT OF HIGH TEMPERATURE MATERIAL EROSIO..(U) SPECTRON DEVELOPMENT LABS INC COSTA MESA CA K D ARUNKUMAR ET AL. APR 86 1/1

UNCLASSIFIED SDL-86-2439-03 AFOSR-TR-86-1053 F/G 14/2 NL



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE

DTIC ELECTE OCT 2 0 1986 S D

(2)

AD-A173 192

REPORT DOCUMENTATION PAGE

1a. REPORT SECURITY CLASSIFICATION: Unclassified	1b. RESTRICTIVE MARKINGS
2a. SECURITY CLASSIFICATION AUTHORITY	3. DISTRIBUTION/AVAILABILITY OF REPORT: Distribution unlimited; approved for public release
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE	
4. PERFORMING ORGANIZATION REPORT NUMBER(S): 86-2439-03	5. MONITORING ORGANIZATION REPORT NUMBER(S): AFOSR-TR- 86-1058
6a. NAME OF PERFORMING ORGANIZATION: Spectron Development Labs; 6b. OFFICE SYMBOL (If applicable)	7a. NAME OF MONITORING ORGANIZATION: Air Force Office of Scientific Research
6c. ADDRESS (City, State and ZIP Code): 3535 Hyland Ave., Ste. 102, Costa Mesa, CA 92626	7b. ADDRESS (City, State and ZIP Code): Bolling AFB DC 20332-6448
8a. NAME OF FUNDING/SPONSORING ORGANIZATION: Air Force Office of Sci. Res.; 8b. OFFICE SYMBOL (If applicable): AFOSR/NA	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER: F49620-85-C-0046
8c. ADDRESS (City, State and ZIP Code): Bolling AFB DC 20332-6448	10. SOURCE OF FUNDING NOS.
11. TITLE (Include Security Classification): "Optical Technique for the Measurement of	

PROGRAM ELEMENT NO.	PROJECT NO.	TASK NO.	WORK UNIT NO.
61102F	2308	A3	

12. PERSONAL AUTHOR(S): K. D. Arunkumar, M. Azzazy, J. D. Trolinger

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Yr., Mo., Day)	15. PAGE COUNT
Annual Report	FROM 3-1-85 TO 3-31-85	April 1986	50

16. SUPPLEMENTARY NOTATION

17. COSATI CODES FIELD	GROUP	SUB. GR.
20	05	
21	03	

18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number): Diffuse Point Interferometer, Holographic Interferometry, Glow Discharge, Vacuum Chamber, Surface Erosion

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

A differential Michelson's interferometer capable of measuring path length variation of the order of 0.002μ has been developed and tested. It has also been proven that this interferometer can be used to measure surface heights on diffuse objects. This ability of the interferometer will be used in profiling surfaces eroded electrically. To generate electrically eroded surfaces, a discharge chamber has been built and tested. Using copper electrodes, glow discharge has been struck and characterized. Work done on an eroded electrode with holographic interferometry shows that overall surface erosion ~ λ can be detected using this technique.

DTIC FILE COPY

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT: UNCLASSIFIED/UNLIMITED ☒ SAME AS RPT. ☐ DTIC USERS ☐	21. ABSTRACT SECURITY CLASSIFICATION: Unclassified
22a. NAME OF RESPONSIBLE INDIVIDUAL: Julian M. Tishkoff	22b. TELEPHONE NUMBER (Include Area Code): (202)767-4935; 22c. OFFICE SYMBOL: AFOSR/NA

DD FORM 1473, 83 APR EDITION OF 1 JAN 73 IS OBSOLETE.

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE

11. (Title Concluded) High Temperature Material Erosion

AFOSR-TR- 86-1058

TABLE OF CONTENTS

86243903tc/48

LIST OF FIGURES

LIST OF FIGURES (CONTINUED)

1.0 WORK STATEMENT AND PROGRAM OBJECTIVES

1.1 Statement of the Problem

Material erosion at high temperatures occurs in various space and missile propulsion systems. For example, magnetoplasmadynamic (MPD) thruster electrodes erode during operation in high temperature plasma environments. Rocket engine nozzles also are subjected to erosive environments by particle laden combustion gases existing in the combustion chamber. Adequate methods for measuring erosion recession in hostile environments is not available to support development testing of propulsion systems. Some components of interest in space applications are acquired to have long lifetimes (10,000 hours or greater). Practical testing of such components require extremely sensitive methods to reduce test times to useful lengths. Present methods used to measure erosion recession include radioactive tracing and quartz crystal microbalances. Both measurements are indirect in so far as they measure loss of mass rather than change in dimension and shape. They are also only used at specific points because they must be implanted into the surface of the material.

Thus, a direct measurement of the shape of the eroding material with sufficiently high resolution would present significant advantages, particularly if it could be used to measure a complete surface rather than a few specific points. The research that is being conducted under this program is anticipated to provide a fundamental understanding necessary for making such measurements with optical techniques.

1.2 Program Objective and Achievements

The objective of the program in the first year was to identify and develop those optical technique(s) that can be used to characterize nonintrusively, eroded surfaces. Three primary optical techniques capable of direct measurement, were examined. They are:

a. Diffuse Point Interferometry
b. Holographic Interferometry
c. Astigmatic Ranging Probe

The feasibility of the last technique in measuring surface movement, to a high precision, has been proven(1). However, its applicability to an eroded surface has been severly restricted due to serious signal to noise ratio problem. Hence, this approach has been ruled out as a viable technique for studying surface recession caused by erosion.

Most of our efforts in the first year have been directed towards developing the Diffuse Point (DiP) interferometer since this interferometer when fully developed can profile the eroded surface down to submicron level. A detailed description of principle of operation of the interferometer and the initial experimental results are reported here.

Some effort has been spent in looking at erode surfaces using holographic interferometry (HI). Results of this preliminary study is also reported here.

Since the primary interest is in electrically eroded surfaces, an experimental test chamber has been assembled to provide an electrical erode on environment similar to that anticipated in electrical propulsion systems. Details of this set up along with the characteristics of the discharge are also included in this report.

2.0 RESEARCH EFFORTS

In this section we discuss in detail the diffuse point intefero-meter, the vacuum chamber, characteristics of the glow discharge and the preliminary HI results obtained on an eroded surface.

2.1 Diffuse Point Interferometry

The interferometer, in principle, is a variation of Michelson's interferometer [2,3]. A lay out of the DiP interferometer is given in Figure 1. The output of this He-Ne laser is polarized 45° with respect to the horizontal plane. The horizontal plane is defined as that plane which contains the beam k vector, detectors and the light source. A polarization sensitive beam splitter (PBS), splits this beam into two beams, one of which is polarized parallel to the horizontal plane (P-polarization) while the other has perpendicular polarization (S-polarization). The optical axis of the Pockel's cell is perpendicular to the plane whereas the Wollaston prism is so oriented as to have its optical axis parallel to the original polarization of the laser beam. The direction of optical axes of different components and the electric vector of the laser beam w.r.t. to an x-y coordinate system is shown in Figure 2. The S polarized reference beam and the P polarized object beam upon passing through the Wollaston prism are optically mixedif the Wollaston optical axis bisects the angle between the S and P polarization. The detectors D_A and D_B will, therefore, sense two signals which are 180° out of phase, such that:

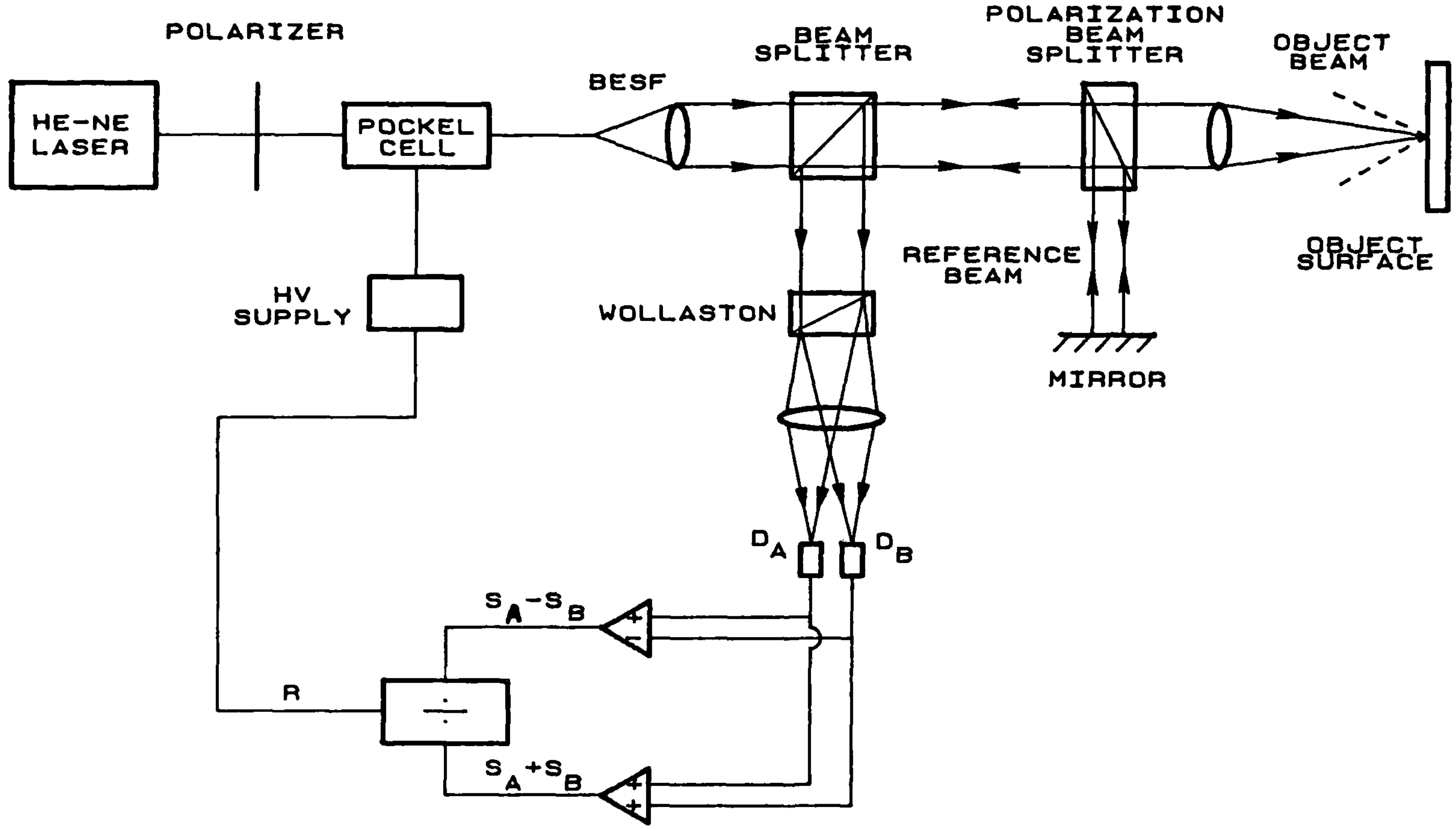


FIGURE 1a. SCHEMATIC OF THE DIFFUSE POINT DIFFERENTIAL INTERFEROMETER

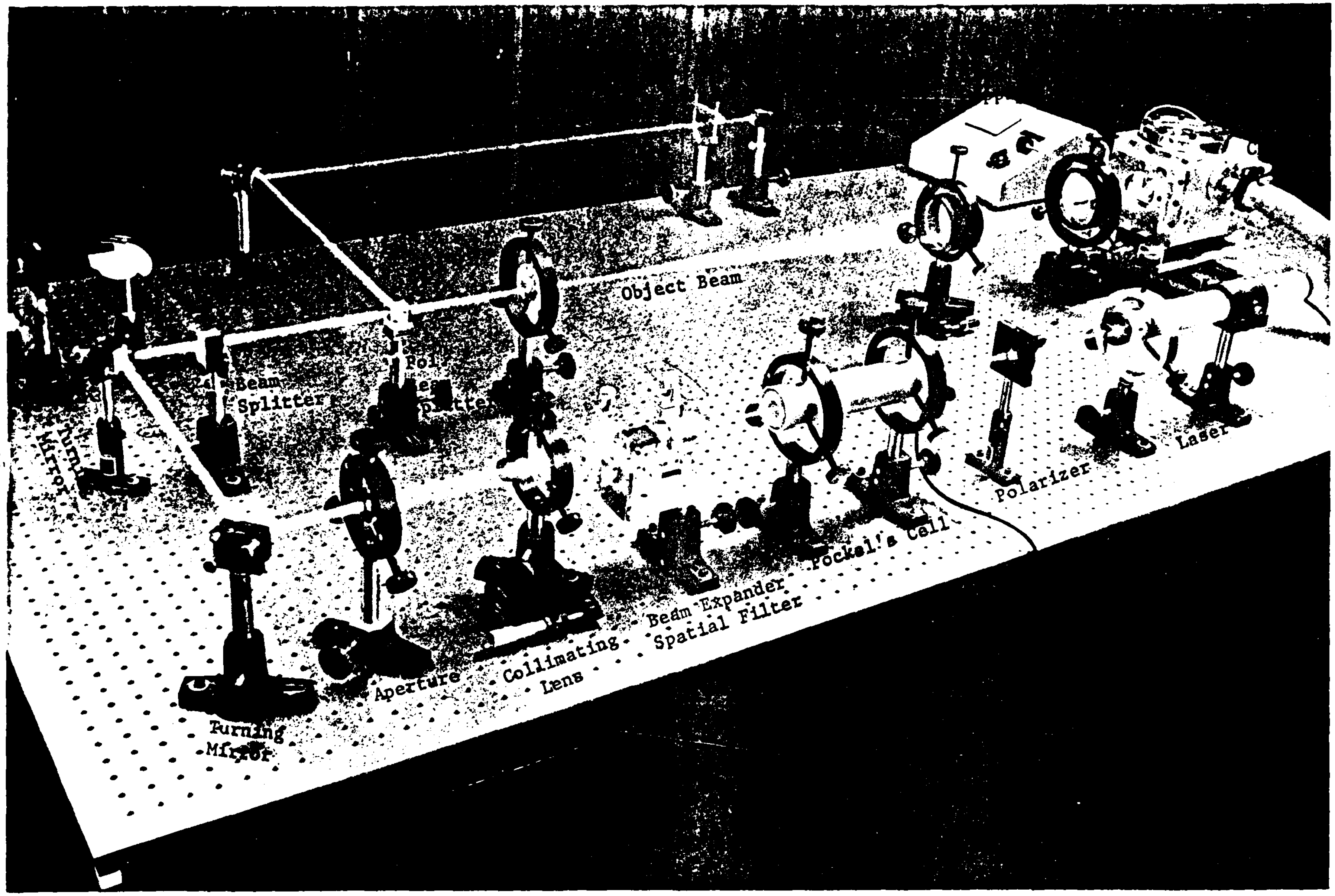


Figure 1b. Diffuse Point Interferometer.

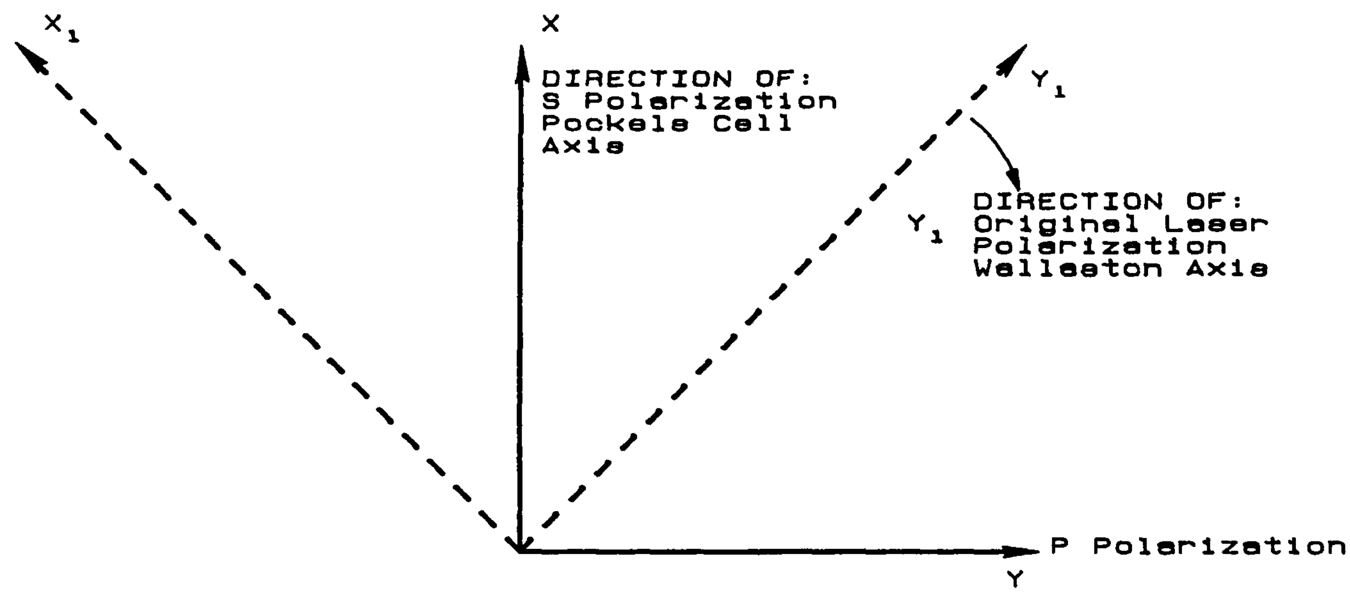


FIGURE 2. COORDINATE SYSTEM

$$\left.\begin{aligned} S_A &= S_o + S_1 \cos(\phi + \gamma) \\ &\text{and} \\ S_B &= S_o - S_1 \cos(\phi + \gamma) \end{aligned}\right\} \qquad (1)$$

where ϕ is the phase difference between the two beams due to path difference and γ is the additional phase introduced to the reference beam by the Pockels cell to achieve phase quadrature condition. S_o is proportional to the input laser power and S_1 is dependent on fringe visibility. When the signals are combined in a difference amplifier, a signal proportional to the cosine of the phase difference is generated, that is:

$$S_c = 2S_1 \cos(\phi + \gamma) \qquad (2)$$

Under phase quadrature condition, i.e., when $\phi + \gamma = \frac{\pi}{2} + 2\, m\, \pi$., the difference signal is zero and the corresponding path difference (introduced by surface features) is $\Delta\ell = \frac{1}{k}(\frac{\pi}{2} - \gamma)$. Knowing the voltage applied to the Pockel's cell γ and/or $\Delta\ell$ can be easily calculated. The voltage to be applied to the Pockel's cell will be determined by the magnitude of S_c. This signal is usually normalized by the sum signal $S_A + S_B$, to reduce the effect of laser power fluctuations. In the following sections, a detailed analysis of the interferometer as applied to polished and rough surfaces are given.

2.1.1 Analysis of DiP Interferometer

2.1.1.1 Mirror Surface

If the object beam is returned from a mirror like surface, the interferometer is identical to Michelson's interferometer. The initial analysis deals with such a surface and later extends the same to a rough surface.

The electric fields entering and leaving the polarizing beam splitter can be represented as:

$$E_s = a_s\, e^{-i(\omega t + kz + \gamma)} \tag{3}$$

and

$$E_p = a_p\, e^{-i(\omega t + kz)} \tag{4}$$

where ω is the laser frequency, k is the wave number, γ is the phase change introduced by the Pockel's cell, and a_s & a_p are the amplitudes of the S and P waves respectively.

These amplitudes will be equal in magnitude if the electric vector incident on the polarizing beam splitter is oriented 45° to the horizontal plane. Since the reflecting surface has mirror like finish, the returning beam can be represented as:

$$E_s^{sc} = E_s e^{-i\delta_x} \tag{5}$$

$$E_p^{sc} = E_p e^{-i\delta_y} \tag{6}$$

where $(\delta_x - \delta_y)/k$ represents twice the path length difference between the object beam and reference beam.

Since the Wollaston prism optical axis is oriented parallel or normal to the oringinal laser beam e vector an interference pattern will occur in the plane of the photodetectors. Using the coordinate system illustrated in Figure 2, the electric field amplitude at the detector plane, E_{sig}, will be:

$$E_{sig} = \frac{1}{\sqrt{2}} \begin{bmatrix} 1 & 1 \\ 1 & -1 \end{bmatrix} \begin{bmatrix} E_s e^{-i\delta_x} \\ E_p e^{-i\delta_y} \end{bmatrix} \tag{7}$$

and the detector signals will be

$$\begin{aligned} S_A &= S_o \, [1 + S_1 \cos(\delta + \gamma)] \\ S_B &= S_o \, [1 - S_1 \cos(\delta + \gamma)] \end{aligned} \tag{8}$$

where $S_o = a_s{}^2 + a_p{}^2$ is the laser power, $S_1 = 2a_s a_p/S_o$ is the fringe visibility and $\delta = \delta_x - \delta_y$.

The quadrature condition is achieved when the phase is an odd multiple of $\frac{\pi}{2}$, i.e.,

$$(\delta + \gamma) = (2n + 1) \; \frac{\pi}{2} \; ; \; n = 0,1,2,... \tag{9}$$

An error signal, $S_- = S_A - S_B$ is used to control the phase γ, introduced by the Pockels cell such that the quadrature condition expressed in Equation (9) is realized. The path difference between the reference and object beams will then be:

$$\Delta = (2n + 1) \frac{\lambda}{4} - \Gamma \qquad (10)$$

where $\Delta = \delta/k$ and $\Gamma = \gamma/k$ and λ is the laser wavelength. Since the introduced phase, γ is linearily proportional to the voltage applied to the Pockels cell, the path difference in the two arms, $\Delta/2$, can be obtained by measuring the voltage on the Pockels cell.

2.1.1.2 Diffuse Surface

When the object surface is a diffuse,reflector the incident P polarized light undergoes diffuse reflection (scattering). Hence, a speckle field appears at the face of the Wollaston prism. This speckle pattern will be a subjective definition one and hence, the size of each speckle is determined by the lens system in the interferometer. Since the minimum deconvolution area of a given diffuse surface is $\sim \lambda$, the number of scatterers responsible for the speckle field is approximately of the order of $(d_o/\lambda)^2$ where d_o is the beam waist at the surface. Assuming that the incident polarization is not changed by scattering, the complex amplitude at the Wollaston prism can be written as [4]

$$E_p^{sc} (x,y,z) = a_p (x,y,z) \exp [-i\delta(x,y,z)]. \qquad (11)$$

This can be represented as a vector in a complex plane as shown in Figure 3. This complex amplitude which contains all the information about the spatial structure of the P polarized light is actually the sum of a large number N of components which represent the light received

$$E_p^{sc}(x,y,z) = \left(\frac{1}{\sqrt{N}} \right) \sum_{n=1}^{N} a_n \exp\left(-i\phi_n\right)$$

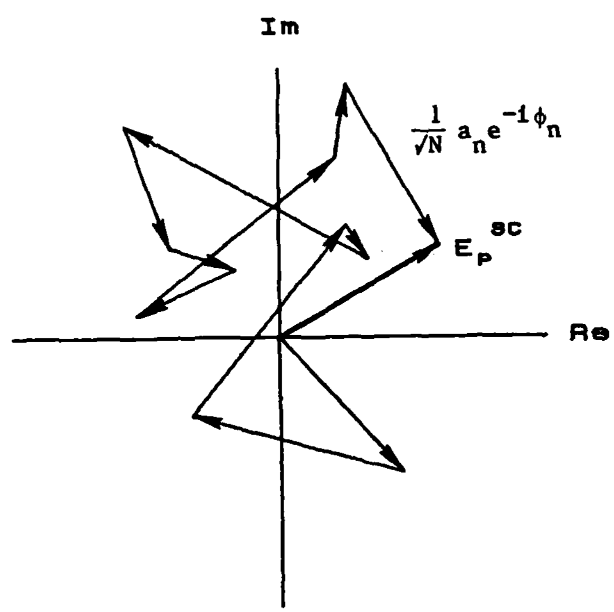


FIGURE 3. ADDITION OF RANDOM PHASOR AMPLITUDES.

from the vicinity of each point of the illuminated diffuse surface. Thus the phasor amplitude of the speckled field at the Wollaston can be written as:

$$E_p^{sc} = \frac{1}{\sqrt{N}} \sum_{n=1}^{N} a_n \exp(-i\delta_n) \tag{12}$$

As in the previous case, the electric field at the detector plane is

$$E_{sig} = \frac{1}{\sqrt{2}} \begin{bmatrix} 1 & 1 \\ 1 & -1 \end{bmatrix} \begin{bmatrix} E_s\, e^{i\delta_x} \\ \frac{1}{\sqrt{N}} \sum_{n=1}^{N} a_n \exp(-i\delta_n) \end{bmatrix} \tag{13}$$

Following the same analysis as before the signal from detector A and B can be written as:

$$S_A = a_s^2 + \frac{1}{N} \sum_{n=1}^{N} a_n^2 + \frac{1}{N} \left[\sum_{\ell=1}^{N-1} a_\ell e^{i\delta_\ell} \cdot \sum_{n=\ell+1}^{N} a_n e^{-i\delta_n} + \sum_{\ell=1}^{N-1} a_\ell e^{-i\delta_\ell} \cdot \sum_{n=\ell+1}^{N} a_n e^{i\delta_n} \right] + \left[\frac{a_s}{\sqrt{N}} e^{i(\delta_x+\gamma)} \cdot \sum_{n=1}^{N} a_n e^{-i\delta_n} + \frac{a_s}{\sqrt{N}} e^{-i(\delta_x+\gamma)} \cdot \sum_{n=1}^{N} a_n e^{i\delta_n} \right] \tag{14}$$

and

$$S_B = a_s^2 + \frac{1}{N}\sum_{n=1}^{N} a_n^2 + \left[\frac{1}{N}\sum_{\ell=1}^{N-1} a_\ell e^{i\delta_\ell} \cdot \sum_{n=\ell+1}^{N} a_n e^{-i\delta_n}\right.$$

$$\left. + \sum_{\ell=1}^{N-1} a_\ell e^{-i\delta_\ell} \cdot \sum_{n=\ell+1}^{N} a_n e^{i\delta_n}\right] - \left[\frac{a_s}{\sqrt{N}} e^{i(\delta_x+\gamma)} \cdot \sum_{n=1}^{N} a_n e^{-i\delta_n}\right. \tag{15}$$

$$\left. + \frac{a_s}{\sqrt{N}} e^{-i(\delta_x+\gamma)} \cdot \sum a_n e^{i\delta_n}\right]$$

The first two terms in (14) and (15) represent the signal dc level and the third term represents the speckle pattern. The fourth term, which is of special interest to our studies represents the interactions of speckles with the reference beam. It can be rewritten as:

$$2\frac{a_s}{\sqrt{N}} \sum_{n=1}^{N} a_n \cos\left[(\delta_x - \delta_n) + \gamma\right] \tag{16}$$

As is evident from the cosine term, achieving phase quadrature condition in the presence of speckle field is not a trivial matter. For large phase excursions of δ_n, fringe visibility will be totally lost. However, if the illuminated spot on the diffuse surface is kept small, say of the order of a few microns, the probability for abrupt change in surface roughness features within the spot can be extremely small (<<1). This is especially true when the surface is eroding and the erosion rate is small. In such a case, one may be justified in assuming the scattered radiation to have minimum spread in its spatial phase information. The cosine term in (16) then can be written as cos $[(\delta_x-\bar{\delta})+\gamma]$ where $\bar{\delta}$ is the mean phase change in the object beam due to

the surface feature heights. Under this condition, phase quadrature may still be achieved, however, fringe visibility will be reduced.

In the next section we present some experimental results that substantiate the above assumption.

2.1.2 DiP Interferometery Calibration and Measurement

The interferometer was calibrated using a mirror like surface and a diffuse surface. The object was mounted on a translation stage that had a sensitivity of 0.25 μ. Figure 4 gives the plot beween the distance the object was moved against the voltage applied to the Pockel's cell for quadrature condition. Calibration points for both mirror and diffuse surfaces lie close to one another supporting the assumption that for small d_o, spread in δ_n is minimum The calibration curve was generated using a laser spot size of 19 μ. Efforts are underway to reduce the focal spot size to 5 μ. If successful, this would further validate our assumption.

2.1.3 Spatial Resolution

The spatial resolution of the interferometer is limited by the size of the focal spot on the target surface. This is at least two orders of magnitude better than what can be achieved with a mechanical profilometer.

2.1.4 DiP Interferometer Sensitivity

Since the translation stage on which the objects were mounted had only a resolution of 0.25 μ, we had to resort to indirect methods to

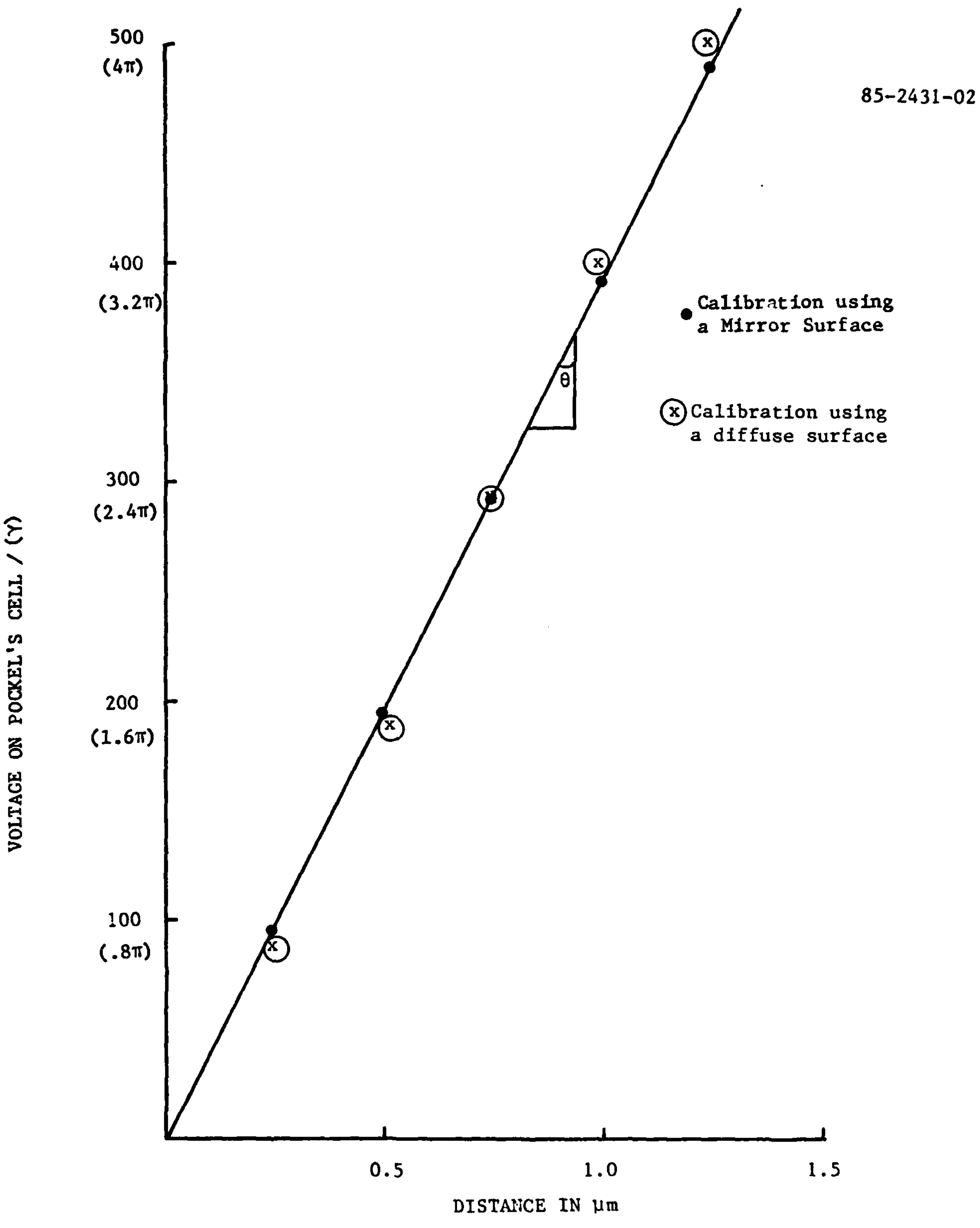


Figure 4. Calibration of the Diffuse Point Differential Interferometer

determine the sensitivity of the interferometer. The methods used involved measuring path length variation induced in the object beam as a result of temperature variation in the air near the surface. A temperature controlled boundary layer was used for that purpose [3] and Figure 5 shows the response of the interferometer to the thermally induced pathlength change. From the curve one can see that the interferometer is capable of responding to a temperature change of 1°C. Since this change corresponded to a path length variation of 0.002 μm. The sensitivity of the DiP interferometer can be taken to be 0.002 μm.[3]

2.1.5 Measurements on Diffuse Surface

After the interferometer was calibrated and its sensitivity determined, measurements were done on three cam surfaces which have already been profiled using a mechanical profilometer. Figures 6-8 compare the profilometer trace against that obtained using the interferometer. The rms values from both measurements were then compared to check the applicability of DiP interferometry to surface profiling. The rms values agree to within ± 5% indicating that diffuse point interferometer can indeed be a viable, noncontact, surface characterization tool.

All the measurements that we have carried out so far are on machined surfaces and not on eroded ones. Since the aim of the program is to look at those surfaces that have been subjected to erosion, we designed and built a system that is capable of producing surface erosion through electrical discharge. This will be detailed in the following section.

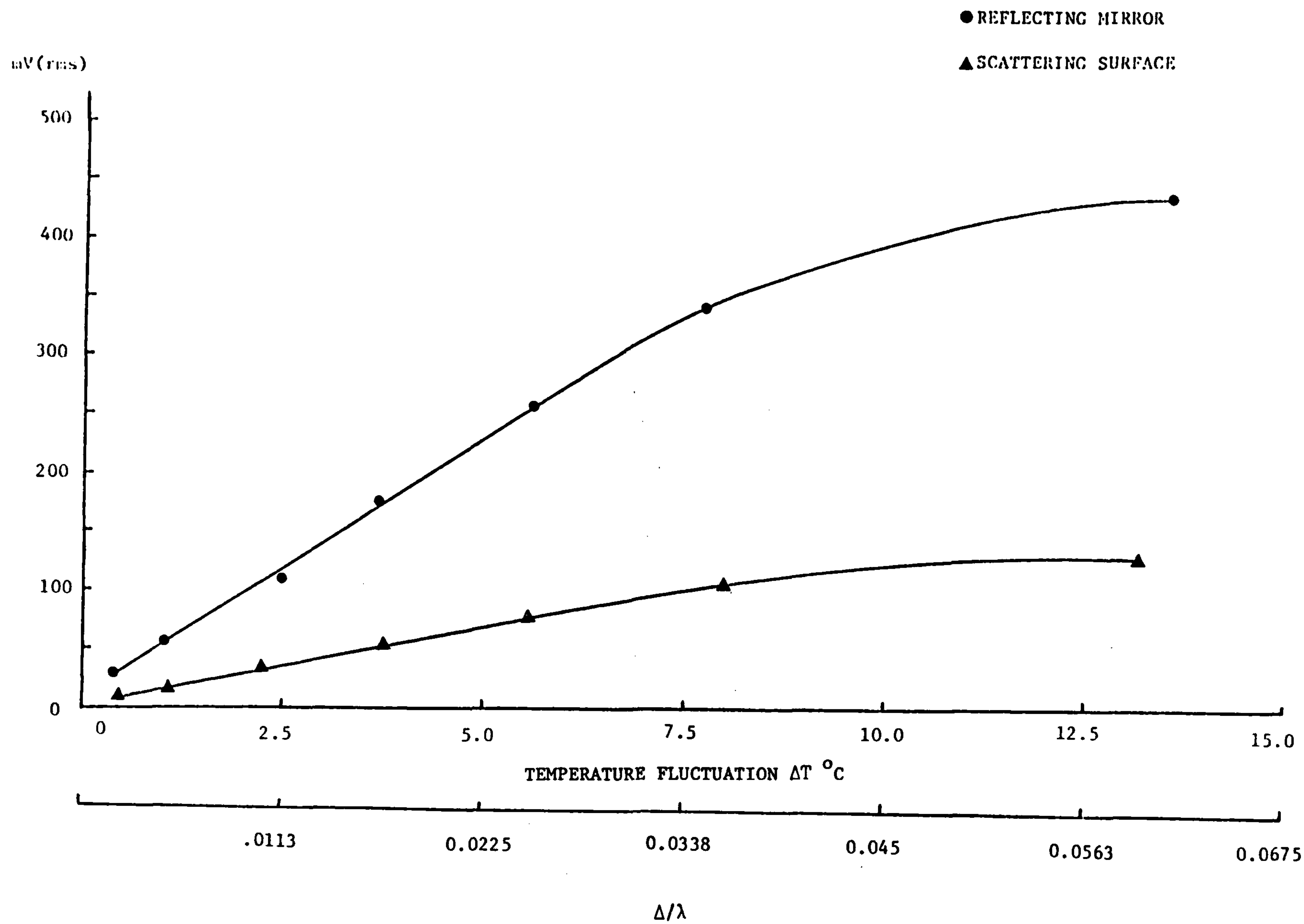


Figure 5. Laser Interferometer Signal rms as a Function of Temperature Fluctuation for Both the Reflecting Mirror and the Scattering Surface

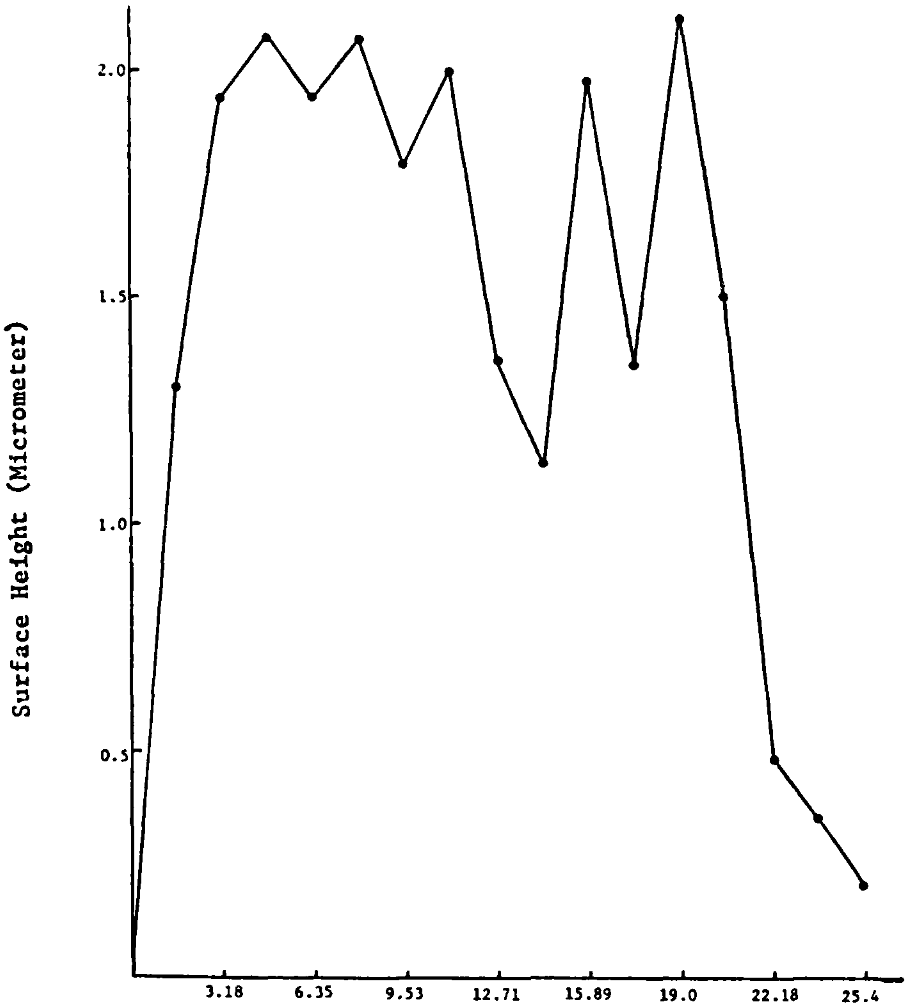


Figure 6a. Injector Lobe Surface Profile After Grinding Process Using Diffuse Point Differential Interferometry. Surface Height rms Value = .645μm

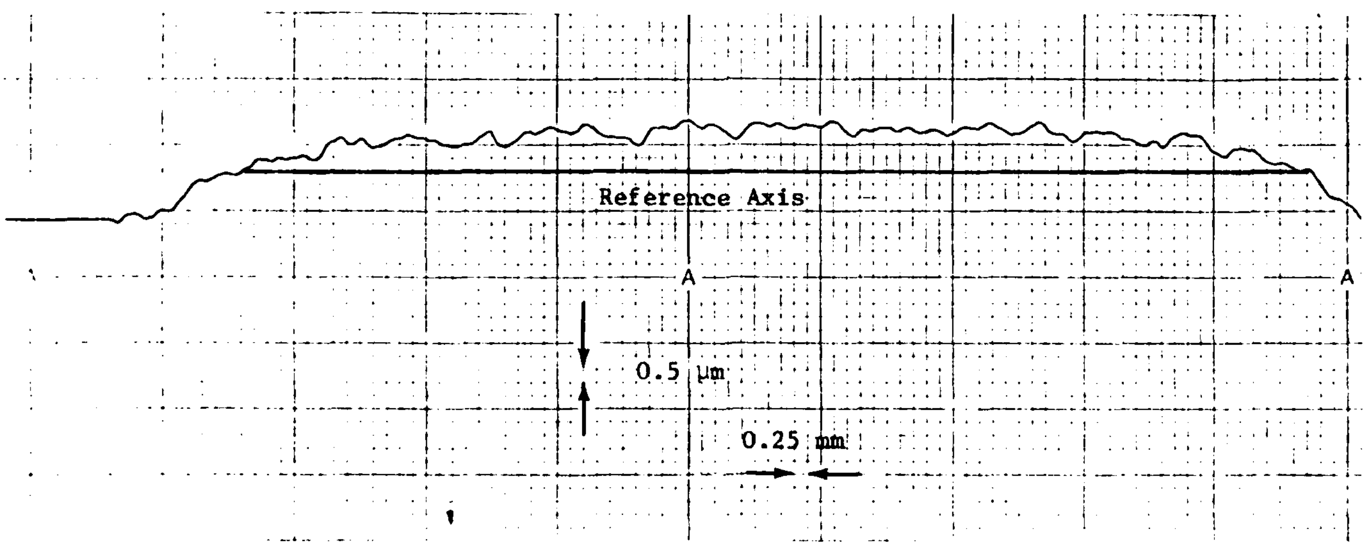


Figure 6b. Injector Lobe Surface Profile After Grinding Process Using a Mechanical Stylus. Surface Height rms Value = .652μm

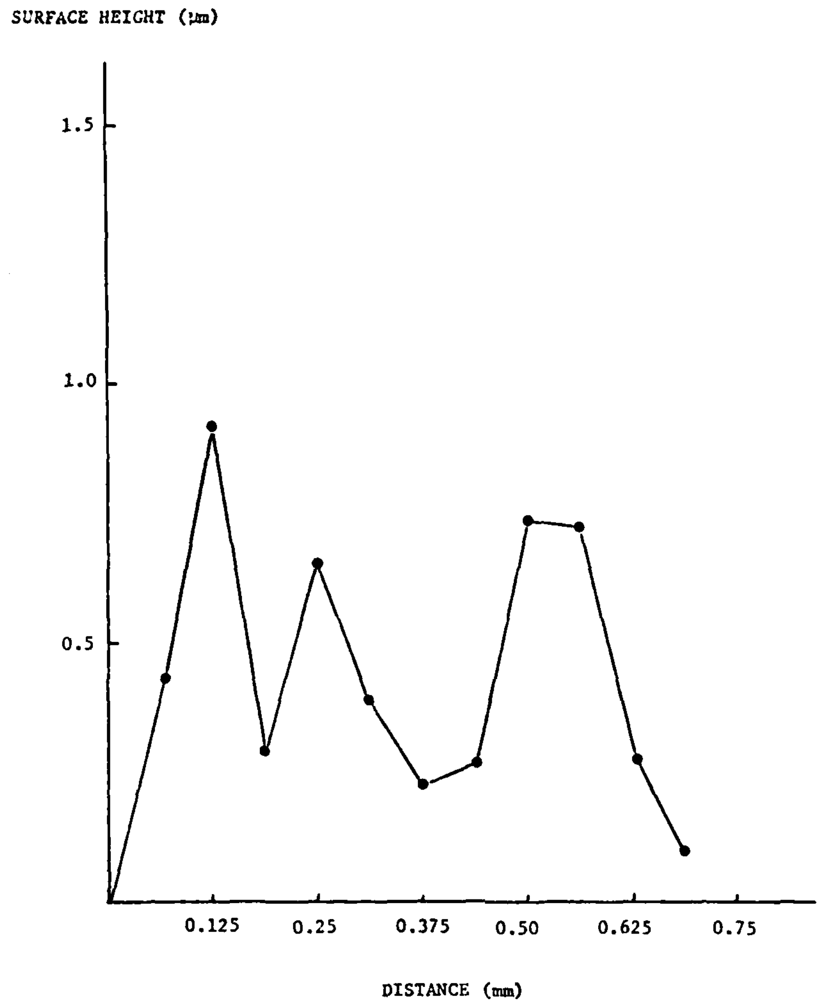


Figure 7a. Cam Surface Profile after Polishing Process Using Diffuse Point Differential Interferometry. Surface Height rms Value = .262 μm

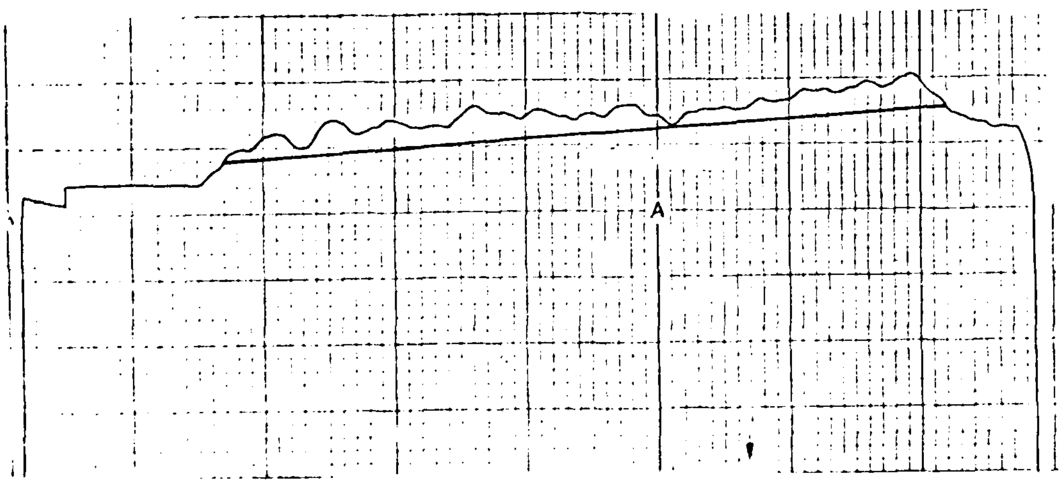


Figure 7b. Cam Surface Profile After Polishing Process Using a Mechanical Stylus. Surface Height rms Value = .259μm

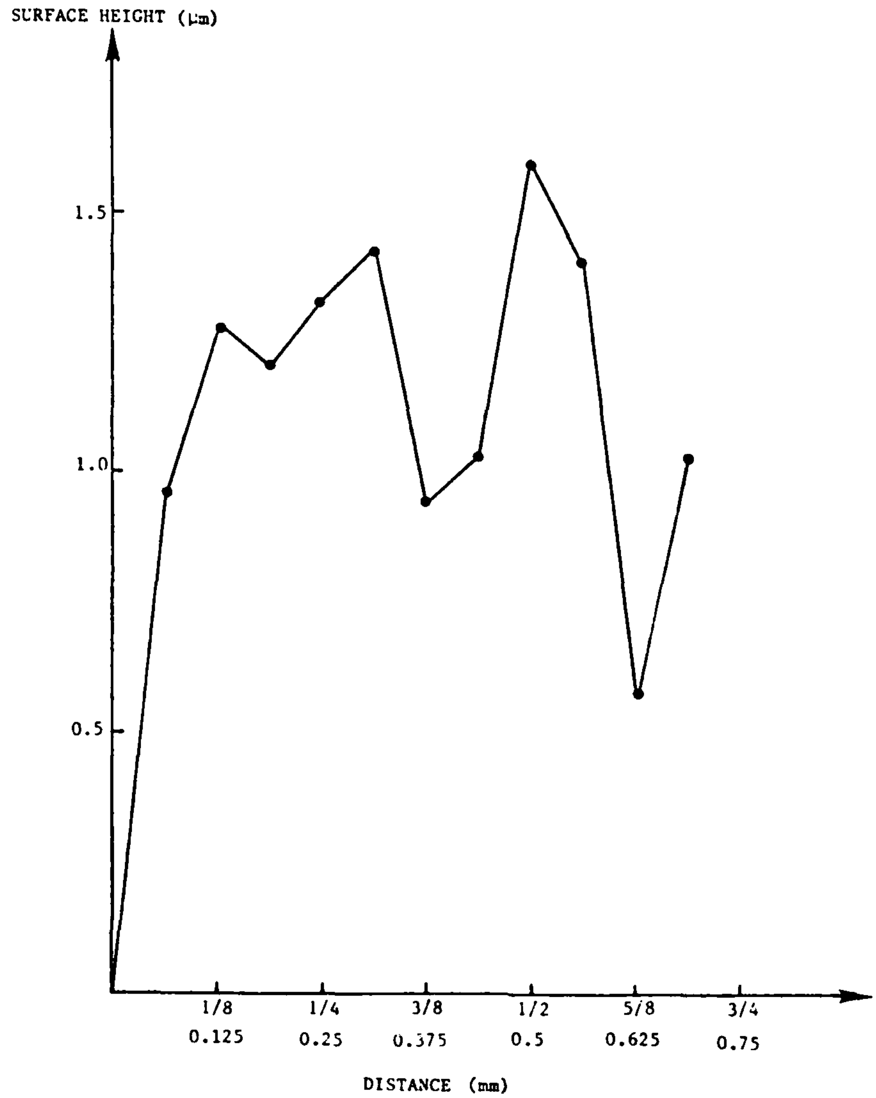


Figure 8a. Cam Surface Profile After Etching Process Using Diffuse Point Differential Interferometry. Surface Height rms Value = .290μm

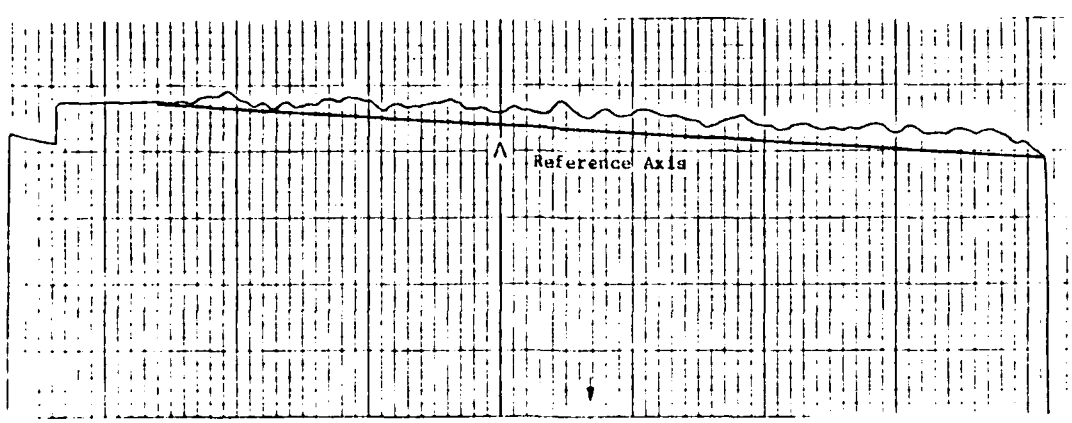


Figure 8b. Cam Surface Profile After Etching Process Using a Mechanical Stylus. Surface Height rms Value = .293μm

2.2 Surface Erosion Through Electrical Discharge

Surface electrical erosion occurs when a surface is exposed to an energetic plasma. For the present experiment, a simple glow discharge was assembled. The discharge is maintained inside an aluminum vacuum chamber which can be pumped down to about 1×10^{-3} torr of pressure. A schematic diagram of the chamber is shown in Figure 9 (Photograph of the chamber in Figure 1b). Two high voltage feed throughs are used to apply the needed voltage to the electrodes. The anode is attached to a push-pull feedthrough and can be moved perpendicular to the cathode. This degree of freedom is required to have optical access to the cathode surface that is to be profiled using the DiP interferometer.

The cathode is mounted such that it can be moved along the beam direction. This movement allows for varying gap distance between the copper electrodes.

The chamber is pumped down using a Varian mechanical pump Model SD-90 and then flushed with Argon gas half a dozen times. After pumping out residual gases, Ar gas is let into the chamber at 1-2 torr pressure. The temperature of the cathode when the discharge is on is monitored with a thermocouple kept in contact with the cathode (not shown in the figure). The electrodes are energized using a 1KV, 15 mA power supply. The resulting glow discharge was characterized under static and dynamic flow conditions. The pertinant parameters of the discharge are listed in Tables 1 and 2. For voltages beyond V_{max}, the discharge becomes unstable and erratic. Figures 10 and 11 give the discharge current as a function of electrode separation. As can be seen

19	1		OPTICAL FLAT
18	1	SDL-1092-C-108	CATHODE PLATE HOLDER
17	1	0531-F0472-303	THERMOCOUPLE GAGE TUBE
16	1	1340-F0205-366	1340 O-RING COMPRESSION SEAL
15	1		WVCR MALE CONNECTOR
14	1	800-1225	LONG WELD STUB FLANGE
13	1	954-5128	GLASS VIEWING PORT
12	1	SDL-1092-C-107	VACUUM CHAMBER COVER #2
11	1	854-5150	LINEAR MOTION FEEDTHROUGH
10	2	954-5219	HIGH VOLTAGE FEEDTHROUGH
9	2	SDL-1092-B-106	ANODE
8	1	SDL-1092-C-105	ANODE PLATE HOLDER
7	1	SDL-1092-C-104	WINDOW HOLDER
6	1	SDL-1092-B-103	GUIDING ROD HOLDER #2
5	1	SDL-1092-B-103	GUIDING ROD HOLDER #1
4	1	SDL-1092-B-102	GUIDING ROD
3	1	1371-F6459-301	PUSH-PULL FEEDTHROUGH
2	1	SDL-1092-D-101	VACUUM CHAMBER
1	1	SDL-1092-C-100	VACUUM CHAMBER COVER #1

Figure 9. Legends

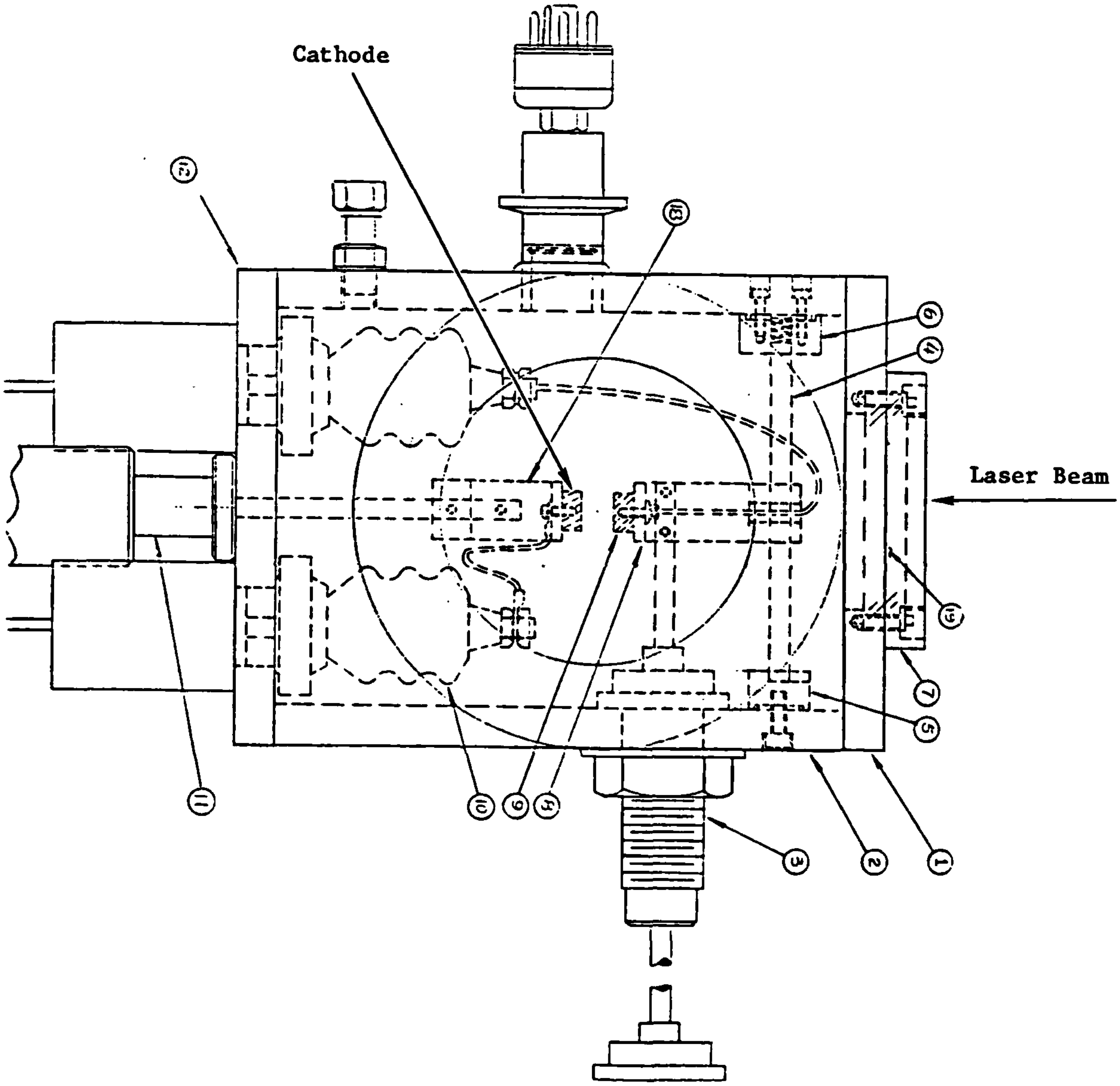


Figure 9a. Top View of the Vacuum Chamber.

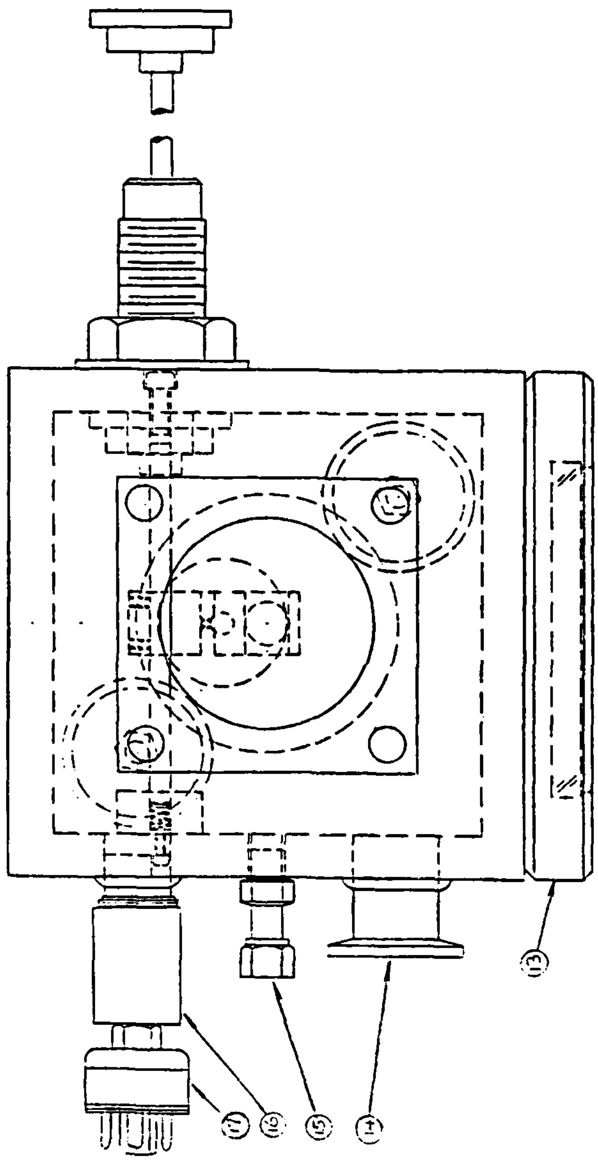


Figure 9b. Side View of the Chamber.

TABLE 1 DISCHARGE PARAMETERS UNDER DYNAMIC FLOW CONDITION

ELECTRODE GAP(mm)	PRESSURE	V_B(Volts)	V_{MIN}(Volts)	V_{MAX}(Volts)	I_{MIN}(mA)	I_{MAX}(mA)
5	1 TORR	240	225	250	1.24	1.33
	2 TORR	290	225	320	0. 3	9.0
10	1 TORR	300	230	310	0.17	2.14
	2 TORR	390	230	325	0.25	>10
15	1 TORR	350	230	320	0.19	2.68
	2 TORR	450	230	328	0.25	>10
20	1 TORR	380	240	335	0.16	3.82
	2 TORR	500	240	303	0. 4	>10

V_B Breakdown voltage

V_{min} Minimum voltage required to sustain a glow discharge

V_{max} Maximum voltage that can maintain a stable discharge

8962439-03t/48

TABLE 2 DISCHARGE PARAMETERS UNDER STATIC FLOW

ELECTRODE GAP(mm)	PRESSURE	V_B(volts)	V_{MIN}(volts)	V_{MAX}(volts)	I_{MIN}(mA)	I_{MAX}(mA)
5	1 TORR	350	235	300	0.15	3.38
	2 TOOR	400	270	320	0.2	4.02
10	1 TORR	390	285	360	.18	3.22
	2 TORR	470	300	410	0.2	10
15	1 TORR	450	265	350	0.2	3.61
	2 TORR	460	310	410	0.2	6.9
20	1 TORR	450	250	370	0.17	5.0
	2 TORR	490	340	410	0.23	3.96

V_B Breakdown voltage

V_{min} Minimum voltage required to sustain a glow discharge

V_{max} Maximum voltage that can maintain a stable discharge

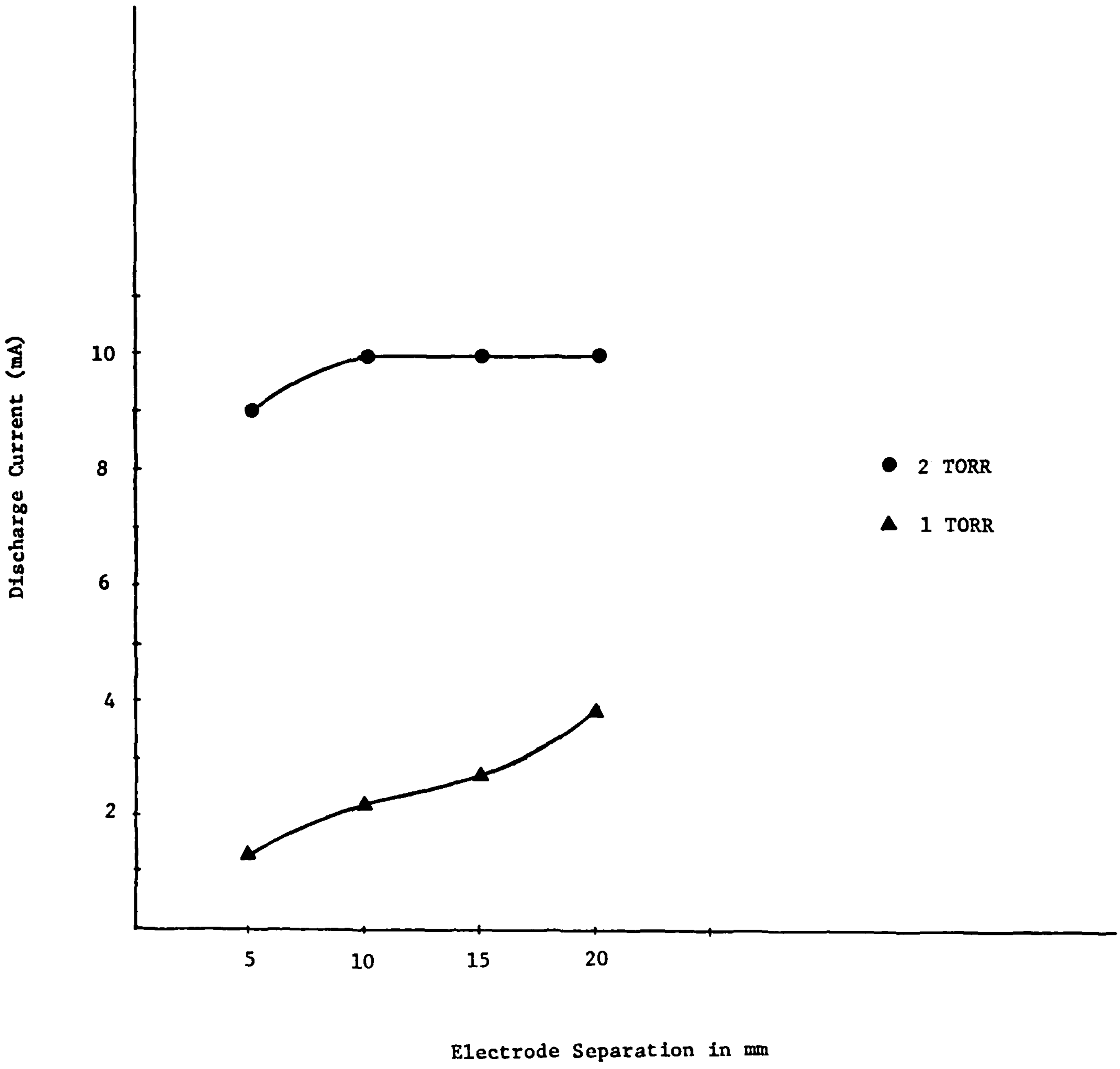


Figure 10. Discharge Current vs. Gap Separation Under Dynamic Flow Condition.

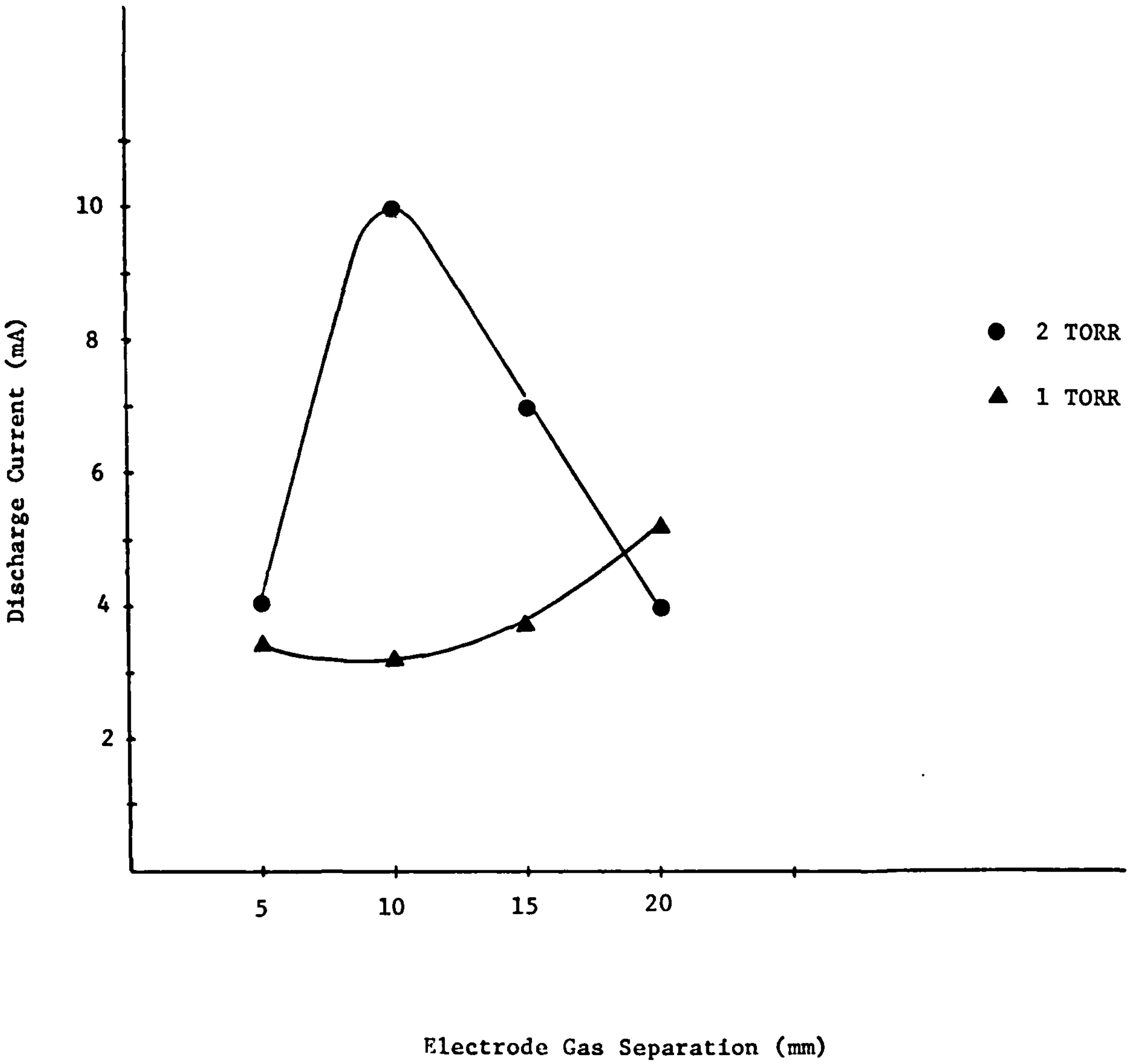


Figure 11. Discharge Current vs. Electrode Separation Under Static Flow Condition.

from the curves, higher discharge currents are attainable at 2 torr pressure and that accelerates surface erosion. However, the electrodes get heated up at a faster rate and the ensuing thermal expansion may be undesirable for holography work. At 1 torr pressure, the discharge current does not exceed 5 mm A. Hence, it will be more appropriate to use 1 torr as the working pressure.

Working under static conditions, we found that the pressure was slowly but steadily increasing due to micro leaks in the chambers. This eventually lead to the destabilization and discoloration of the glow discharge. However, under dynamic condition, i.e., with a steady flow of Ar gas, a well stabilized glow discharge could be subtained for periods longer than 16 hours. Since the required flow rate is only of the order of few milliliters/minute, we prefer the latter.

2.3 Holographic Interferometery

Real time holographic interferometry (HI) has been carried out on an eroded cathode surface. Unwanted fringes generated by thermal expansion of the cathode prevented us from having high current glow discharge. However, low current, glow discharge could be sustained over long periods without any serious thermal expansion problem. Holograms of the surface were made before and after the discharge. At sixteen hours, 1.2 mA discharge generated four interference fringes indicating that the cathode surface had eroded through 2 μ. A detailed analysis of this study along with our on going work with sandwich holography will be reported later.

3.0 SIGNIFICANT ACCOMPLISHMENTS

The most significant achievement in this program so far is the understanding and development of the Diffuse Point Interferometer. This in conjunction with the vacuum chamber, where controlled surface erosion is possible brings us closer to the program objective of developing an optical technique that can nonintrusively monitor surface erosion. Also the preliminary results from the holographic interferometer study shows that HI can detect overall surface recession of the order of λ. These achievements are itemized below.

Specifically, the following tasks were achieved:

1. A test chamber with sufficient optical access and complete control of the electrode location has been designed, constructed and tested.

2. Performance evaluation of the test chamber was achieved experiementally. Characterization of the discharges as a function of electrodes voltage, current, chamber pressure and electrode gap were performed under static 2 dynamic flow conditions.

3. Established the DiP as a viable technique for measuring diffuse surface profiles with a sensitivity of 0.002 μ.

4. Established holographic interferometry as an alternative candidate to DiP for surface erosion monitoring.

5. Use holographic interferometry to obtain detailed surface profile of eroded electrodes.

4.0 PROPOSED EFFORTS FOR THE SECOND YEAR

- Generate eroded surfaces under various discharge conditions.
- Apply DiP interferometry to profile the surfaces
- Apply sandwich holography to study surfaces when at high temperatures
- Study more than one cathode material

5.0 REFERENCES

1. J. Doty, "Astigmatic Noncontract Optical Ganging" Final Report, Submitted to National Science Foundation, 11 April 1983. SDL No. 83-2265-1F.

2. G. Smeets and A. George, "Instantaneous Laser Doppler Velocimeter Using a Fast Wavelength Track Michelson Interferometer", Rev. Sci. Instru., Vol. 49, 11 pp 1589 (1978).

3. M. Azzazy, D. Modarress, and T. Hoeft, "High Sensitivity Boundary Layer Transition Detector", SPIE 29th International Symposium, SPIE (1985). Also submitted to the Journal of Physics E (1985).

4. J. W. Goodman, "Some Fundamental Properties of Speckle", J. Opt. Soc. Am., Vol 66, p. 1145, 1976.

6.0 TECHNICAL ARTICLE IN PREPARATION

"Surface Topography Using Diffuse Point Differential Interferometry", to be submitted to Applied Optics.

7.0 LIST OF PERSONNEL ASSOCIATED WITH THE PROGRAM

The scientists involved in this program are Dr. K. A. Arunkumar, Dr. M. Azzazy, Dr. J. D. Trolinger. The resume's of these persons along with their lists of publications are given below.

DR. K. A. ARUNKUMAR **SENIOR SCIENTIST**

University of Kerala (India)	B.Sc. (1969), Physics
University of Kerala (India)	M.Sc. (1971), Solid State Physics
I.I.T. (Madras, India)	Ph.D. (1976), Magneto-optics
University of Hull (England)	Ph.D. (1979), Applied Physics

Dr. Arunkumar is a physicist with interests in optics, lasers, application of lasers, spectroscopy, holography and fiber optics. He has been involved in the design and development of optical instrumentation for application in the fields of magneto-optics, electro-optics, surface analysis, plasma diagnostics and other high technology areas.

Dr. Arunkumar joined Spectron Development Laboratories, Inc. (SDL) in December of 1984 and is involved in their optical design and inspection programs involving holography. He is also associated with preposing and design fiber-optic based sensors and optical instrumentations.

Before joining SDL, Dr. Arunkumar was with Apollo Lasers Inc., an Allied company, as their Senior Design Engineer. There he was in charge of design and development of new solid state scientific laser systems.

From 1979 to his joining Apollo Lasers, he had been associated with the University of Kentucky where he worked as Assistant Research Professor. There he developed the technique for measuring Normal Unenhanced Raman Scattering (NURS) from very low polarizability molecules adsorbed on surfaces. His invention, capable of altering the temporal characteristics of a pulsed laser, is currently patent pending.

Dr. Arunkumar is listed in Who's Who in the World, Personalities of America, and Who's Who in Frontier Science and Technology. He has also been appointed as an Adjunct Assistant Professor at the University of Kentucky.

CURRENT ACTIVITIES:

Dr. Arunkumar is currently working in the Optics Technology group with optical design and inspection programs for Spectron Development Laboratories, Inc.

PROFESSIONAL SOCIETY AFFILIATIONS:

American Physical Society
Optical Society of America

PATENTS:

"Tunable Integrated Dye-Cell for Q-Switching and Mode-Locking of a Solid State Laser" - Patent Pending.

"Fiber-Optic Magnetic Field Sensor" - Patent Pending.

PUBLICATIONS:

"Photoelectric Detection System for Faraday R tation", Ind. J. Pure and Appl. Phys., Vol. 11, 417, 1973.

"Faraday Effect in Molecules", Ind. J. Phys., Vol. 48, 486, 1974.

"Faraday Rotation in Optically Active Crystals", Proc. Nuclear Physics and Solid State Physics Symposium, Vol. 16C, 118, 1973.

"Magnetic Gyration of Mixed Crystals of Sodium Chlorate and Sodium Bromate", Optica Acta, Vol. 23, 209, 1976.

"Optical Rotation of Solid Solutions of Sodium Chlorate and Sodium Bromate", Phys. Chem, Solids, Vol. 37, 799, 1976.

"A New Physical Technique for the Detection of Carbamate Particles in Water at Low Concentrations", presented at the APS Meeting in Dayton, Ohio in 1981.

"Effect of Microwave Radiation on Chemical Reactions", presented at the Washington Meeting of APS, April 1980.

"A Feasibility Study of a Recombination Laser Operating in the 40A Region using MgXII or AlXIII Ions", Dissertation, University of Hull, Hull, England, 1979.

"Dependence of Satellite Pulse Occurrence on Gain Bandwidth of a Passively Mode-Locked Laser", J. Optics (France), Vol. 12, 197, 1981.

"Raman Spectra of CO Adsorbed on Ni (100)", Spectroscopy Letters, Vol. 15, 113, 1982.

"Theory of Surface Enhanced Raman Scattering", J. Chem. Phys. Vol. 78, 2882, 1983.

"Raman Studies of Oxygen on Ni (111)", presented at the International Conference on Phase Transitions on Surfaces, p. 57, Orono, Maine, August, 1981.

"Low Frequency Raman Spectra of CO adsorbed on Ni (110)", presented at the Washington Meeting of the APS in April, 1982.

"Raman Band Shapes from CO adsorbed on Ni (111), Ni (110) and Ni (100)", in Spectral Line Shape, Vol. 2, p. 625, 1983. Published by Walter de Gruyter & Company, Berlin, New York.

"Raman Spectra of Acetone on Ni (100) and Ni (111)", presented at the APS meeting in Philadelphia in November 1982.

"Low-Frequency Raman Spectrum of CO Adsorbed on Ni (111)", presented at the general meeting of APS in April 1983.

"A UHV cell for Raman Studies of Gases Adsorbed on Metals", Rev. Sci. Instrum., Vol. 55, p. 905, 1984.

"Can Atomic Scale Roughness Features Contribute to Surface Enhanced Raman Scattering?", submitted.

"Raman Spectra of CO and O2 Adsorbed on Single Crystals of Nickel". Proceedings of SPIE - The International Society for Optical Engineering, Vol. 482, p. 130, 1984.

"Normal Unenhanced Raman Spectra of CO and Residual Gas," Surface Science, Vol. 147, p. 477, 1984.

"Normal Unenhanced Raman Spectra of CO and CH4 Adsorbed on Cobalt Crystal (Poly)". Presented at Laser '84 conference in San Francisco, Nov. 1984. Also in Spectroscopy Letters, Vol. 18(3), p. 189, 1985.

"Holographic Interferometry Technique to Detect Defects in Printed Circuit Boards," to be presented at the SPIE Conference in San Diego, August 1986.

"An Ultrasensitive Fiber-Optic Magnetic Field Sensor" J. Op. Soc. Am. A, Vol. 2, p. P67, 1985.

"A Sensitive Fiber-Optic Accelerometer," Presented at the International Conference on Lasers '85, Las Vegas, Nevada, December 1985.

"A Novel Design for a Ruby Laser Oscillator," Presented at the International Conference on Lasers '85, Dallas, Texas, November 1985.

TECHNICAL REPORTS

"Feasibility Study for the Application of Holographic Techniques for Non-Destructive Quality Inspection of Shape Charge Warheads" - Final Report prepared for Mason & Hanger, Silas Mason Co., Inc. Middletown, IA, 1985.

"Power Transistor Stressing - A Preliminary Study Using Holographic Interferometry" - Submitted to Honeywell Inc. Underseas System Division, Hopkins, MN, 1985.

"Holographic Inspection of Printed Circuit Boards" - Submitted to Wright-Patterson Air Force Base, 1986.

DR. MEDHAT AZZAZY **SCIENTIST**

Cairo University, Egypt:	B.S. (1975), Mechanical Engineering
Cairo University, Egypt:	M.S. (1977), Mechanical Engineering
University of California, Berkeley:	Ph.D. (1982), Mechanical Engineering

Dr. Azzazy's responsibilities at Spectron Development Laboratories, Inc., (SDL) include research in the areas of combustion and combustion diagnostics. His current responsibilities include particle and spectroscoptic measurements in flames and theoretical investigations in combustion. He was involved in the temperature measurements of pulverized coal combustion and the characterization of soot particles during the combustion of broad specification gas turbine fuels. He is also involved in developing a resonant holography technique and its applications to turbulent reactive flows.
While at the University of California, Berkeley, Dr. Azzazy conducted extensive research on the experimental and theoretical aspects of turbulent premixed flames.

Dr. Azzazy has developed the method of Laser Induced Fluorescence spectroscopy (LIFS) and then applied it to measure the number density of the hydroxyl radical in Turbulent Premixed Flames. Also he has applied the method of Rayleigh scattering to measure the gas density in the same flame. He has also developed a statistical theory for turbulent flame propagation using a PDF transport equation. The theory was further extrapolated to accommodate for the chemical kinetics.

During the period of 1972 to 1981, Dr. Azzazy has held several assignments in industry and at the University. Dr. Aazzazy has participated in the investigations of steel heat treatment (Voest Iron and Steel, Austria) and the operation of electric power plants (Electricite et gas de France). Also, he has conducted heat transfer computations for cable

de France). Also, he has conducted heat transfer computations for cable car gripping under different loading conditions (City of San Francisco). Dr. Azzazy also participated in designing and teaching undergraduate courses in thermal systems (San francisco State University) and fluid mechanics and aerodynamics (Cairo University, Egypt).

A list of publications is given below.

PUBLICATIONS:

"Laser Induced Fluorescence Measurements of OH in a Turbulent Flame - A Feasibility Study," 20th AIAA Aerospace Sciences Meeting, Florida, Paper AIAA 82-0239 (1982).

"Fluorescence Measurements of OH in a Turbulent Flame," with J. W. Daily, AIAA Journal, Vol. 21, No. 8, (1982).

"Theoretical and Experimental Investigations of Turbulent Premixed Flames," with J. W. Daily and M. Namazian, presented at the 9th International Colloqium on Dynamics of Explosions and Reactive Systems, Poitier, France (1983).

"Laser Diagnostics Methods/A Summary," with J. Trolinger, D. Modarress, and J. E. Craig, presented at AIAA Plasma Sciences Meeting, Paper AIAA-83-1683, also appeared in Lasers in Fluid Mechanics and Plasma Dynamics, ed. C. P. Wang (1983).

"Temperature, Concentration and Size Measurements in Turbulent Reactive Flows," with J. E. Craig, presented at the 20th JANNAF Combustion Meeting, October (1983).

"Resonant Holographic Tomography for Detection of Hydroxyl Radicals in Reacting Flows," with J. E. Craig and C. C. Poon, presented at AIAA 22nd Aerospace Sciences Meeting, AIAA-84-0202 (1984).

"The Effect of Reactive Intermediates on the Propagation of Turbulent Premixed Flames," with J. W. Daily, AIAA Journal, Vol. 23, No. 8 (1985).

"High Sensitivity Boundary-Layer Transition Detector," with D. Modarress and T. Hoeft, Technical Symposium, SPIE, No. 569-08 (1985)

"Characterization of Suspended Particulates on Multicomponent Systems Using Polarization Intensity Ratio and Pointer Beam Techniques", with C. F. Hess, 29th International Technical Symposium, SPIE, No. 573-06 (1985).

"The Effects of Reactive Intermediates on the Propagation of Turbulent Premixed Flames Comparison of Experiment and Theory," with J. W. Daily and M. Namazian, accepted for publication in Combustion and Flame, December (1985).

"Resonant Holographic Detection of Hydroxyl Radicals in Reacting Flows," with J. E. Craig and C. C. Poon, accepted for publication AIAA Journal, February (1986).

"Boundary Layer Transition Detection Using Differential Interferometry", with D. Modarress and T. Hoeft, submitted to the Journal of Physics, E (1985).

TECHNICAL REPORTS:

"Soot Formation and Burnout During the Combustion of Broad Specification Gas Turbine Fuels," with G. S. Samuelsen, SDL Report No. 82-2138-25F, Final Report to AFESC, Tyndall AFB. (1983)

"Particulate Processes in Pulverized Coal Flames," with J. E. Wuerer and R. H. Henze, SDL Report No. 83-2177-49F, Final Report to DOE (PETC). (1983)

"Combustion Measurements with a New Laser Technique," with J. E. Craig, SDL Report No. 83-2266-02F, Final Report to NSF. (1983)

"Notes on Particle Sizing Techniques," Short Course Notes, SDL NO. 83-61029, July. (1983)

"Characterization of Suspended Particulates on Multicomponents Systems," Final Report to NSF, SDL No. 85-2369-02F. (1984)

"Diffuse Point Differential Interferometry for Contouring the Surface Profile of Camshafts", Final Report to Cummins Diesel Engine Company, SDL No. 85-2431-02F (1985).

"Feasibility Study of Optical Boundary Layer Transition Detection Method", with D. Modarress and J. D. Trolinger, Final Report to NASA Langley Research Center, SDL No. 85-2285-47F, (1985).

DR. J.D. TROLINGER **VICE PRESIDENT AND R&D DIRECTOR**

University of Tennessee:	B. S.	(1963), Engineering Physics
Louisiana State University:	M. S.	(1967), Physics
University of Tennessee:	Ph.D.	(1967), Physics

Dr. Trolinger is an applied physicist with special interest in the application of lasers, optical instrumentation, and optical data processing and holography.

Dr. Trolinger joined SDL in May 1975 and is Chief Scientist. His work primarily involves the development and application of optical instrumentation for particle field analysis, flow diagnostics and non-destructive evaluation. His experience includes the development and use of instrumentation for studies in high energy chemical lasers, internal combustion engines, wind tunnels, gun ranges, meteorological facilities, plasma diagnostics, ships, aircraft and manufacturing facilities.

Prior to joining SDL, Dr. Trolinger was Manager of the Science Applications, Inc. (SAI) Optics and Acoustics Applications Laboratory wherein he was responsible for technical direction of programs related to laser instrumentation, coherent and incoherent optical data processing and acoustical imagery. During this time, he developed and implemented the first airborne holocamera system for use in cloud particle measurement. The system was flown successfully in Guam, Kwajalein, and Wallops Island testing.

Prior to joining SAI, he was a member of the technical staff of Arnold Research Organization, Inc. (ARO) at the USAF Arnold Engineering Development Center (AEDC). He headed the ARO, Inc. Laser Applications Committee. He and his team developed and fielded over twenty different laser systems for applications in the AEDC ground test facilities.

He has served as a consultant to the NATO Advisory Group for Aerospace Research and Development and currently acts as an Editorial Advisor for "Lasers and Applications", a monthly periodical. He was an associate professor (part time) in the department of physics, University of Tennessee, where he taught coherent optics and electro-magnetic theory.

A partial list of Dr. Trolinger's publications follows:

PUBLICATIONS:

Periodical Literature

"Multiple Exposure Holography of Time Varying Three-Dimensional Fields," with W. M. Farmer and R. A. Belz, Applied Optics, 1968.

"Wide View Angle Holocamera," Applied Optics, April 1969.

"Holographic Techniques for the Study of Dynamic Particle Fields," Applied Optics, May 1969.

"Holographic Color Schlieren," Applied Optics, October 1969.

"Applications of Holography in Environmental Science," Journal Inst.Envir. Science, October 1969.

"Conversion of Large Schlieren Systems to Holographic Visualization Systems," Fundamentals of Aerospace Instrumentation, Vol. 2, 1969, Instrument Society of America 15th National Symposium 1969.

"Aerodynamic Holography," Aeronautics and Astronautics, November 1972.

"Resolution Factors in Edgeline Holography," with T. H. Gee, Applied Optics, June 1971.

"Applications of In-Line Holography and Generalized Holograhic Flow Visualization," AGARD Lecture Series 49, Laser Technology in Aerodynamic Measurements, 1972.

An Airborne Holography System for Cloud Particle Analysis in Weather Studies," Instrument Society of America, ISA Report No. 74-627, 1974.

J. D. Trolinger, H. T. Bentley, A. E. Lennert and R. E. Sowls, Application of Electro-Optical Techniques in Diesel Engine Research," SAE Journal.

"Flow Visualization Holography," Journal of Optical Engineering, October 1975.

"Airborne Holography Techniques for Particle Field Analysis", Annals of the New York Academy of Sciences, Vol. 276, pp. 448-459, 30 January 1976.

"Particle Field Holography," Journal of Optical Engineering, October 1975.

"Holographic Interferometry as a Diagnostic Tool for Reactive Flows," Journal of Combustion Science and Technology, Vol. 13, 1976.

"Particle Field Diagnostic Systems for High Temperature/Pressure Environments," with W. D. Bachalo, Proceedings of Instrument Society of America Symposium on Instrumentation for Analysis and Control of Coal Fired Combustion Plants, December 1977.

"Diagnostics of Turbulence by Holography," with G.D. Simpson, Optical Engineering, Vol. 18, No. 2, March-April 1979.

"Application of Generalized Phase Control During Reconstruction to Flow Visualization Holography," Applied Optics, Vol. 18, No. 6, 15 March 1979.

"Stresses During Small Motions," Industrial Research/Development, May 1979.

"The Study of Coal Particle Basic Combustion Processes by Holography,"with M.P. Heap, Applied Optics, June 1979.

"Particle Field Diagnostics by Holography," with D. Field, AIAA-80-0018, presented at the AIAA 18th Aerospace Sciences Meeting, Pasadena, California, January 14-16, 1980.

"Analysis of Holographic Diagnostics Systems," Optical Engineering, September 1980.

"Holographic Studies of the Vapor Explosion of Vaporizing Water-in-Fuel Emulsion Droplets," with Stephen A. Sheffield and C. F. Hess, Proceedings of the Second International Colloquium on Drops and Bubbles, p.112, Nov. 19-21, 1981.

"A Statistical Analysis of a Holographic System Intended for the Space Shuttle," with B. P. Hildebrand, AIP Conference Proceeding Series, Encinitas, CA, August 1980, Applied Optics, November 1983.

"Aero-Optical Characterization of Aircraft Optical Turrets by Holography Interferometry and Shadowgraph," in Aero-Optical Phenomena, Vol. 80, Progress in Astronautics and Aeronautics, edited by K. G. Gilbert and J. Otten (1982).

J. D. Trolinger, B. S. Hockley, and J. L. Doty, "Putting Holographic Inspection Techniques to Work," Lasers and Applications, November 1982.

"Multiple Cavity Lasers for Holography," Optical Engineering, January 1984.

"Laser Diagnostic Methods - a Summary," with J. E. Craig, AIAA 16th Fluid Dynamics Conference Proceedings, July 1983.

J. D. Trolinger, B. S. Hockley, and J. L. Doty, "Holographic Nondestructive Inspection: Applications, Capability, and Limitations," International Advances in Nondestructive Testing, Vol. 10, pp. 135-157, 1984.

J. D. Trolinger, C. F. Hess, "Particle Field Holography Data Reduction by Fourier Transform Analysis", Optical Engineering, to be published May 1985.

J. D. Trolinger, "Particle and Flow Field Holography - A Critical Summary", presented SPIE, 1985, Los Angeles Technical Symposium, 20-25 January, 1985.

"Tomographic Reconstruction of Three-Dimensional Flow Over Air Foils", with D. Modarress, H. Tan, SDL and Y. Yu, NASA Ames Research Center, AIAA-85-0479, AIAA 23rd Aerospace Sciences Meeting, Jan. 14-17, 985, Reno, Nevada.

"Dual thermoplastic holography recording system", J. D. Trolinger, H. L. Umstatter, J. L. Doty, Optical Engineering, to be published May, 1985.

"Non Destructive Evaluation by Holography," Advances in Non Destructive Evaluation, to be published in November 1983.

"Development of Holographic Interferometry for Welding Arc Analysis," Proceeding Laser Institute of America, 1983 International Congress on Applications of Lasers and Electro-Optics, with J. F. Key, November 1983.

Other Publications

"Laser Instrumentation for Flow Field Diagnostics," AGARDograph No. 186, published by the North Atlantic Treaty Organization, 1974.

AGARDography in Progress.

Holography for Scientists and Engineers, Academic Press, in progress.

8.0 PAPER PRESENTED AT MEETINGS, CONFERENCES, SEMINARS, ETC.

The results of our work had not been reported in any meeting.

9.0 NEW DISCOVERIES, INVENTIONS OR PATENT DISCLOSURES AT SPECIFIC APPLICATION STEMMING FROM THE RESEARCH EFFORT

The DiP interferometer developed can be applied to surface measurements where high accuracy is needed. We are looking at the possibility of patenting this interferometer.

END

12-86

DTIC